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● *Review*

APPLICATION OF ULTRASOUND IN THE ASSESSMENT OF PLANTAR FASCIA IN PATIENTS WITH PLANTAR FASCIITIS: A SYSTEMATIC REVIEW

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Abstract—Plantar fasciitis (PFS) is one of the most common causes of heel pain, estimated to affect 10% of the general population during their lifetime. Ultrasound (US) imaging technique is increasingly being used to assess plantar fascia (PF) thickness, monitor the effect of different interventions and guide therapeutic interventions in patients with PFS. The purpose of the present study was to systematically review previously published studies concerning the application of US in the assessment of PF in patients with PFS. A literature search was performed for the period 2000–2012 using the Science Direct, Scopus, PubMed, CINAHL, Medline, Embase and Springer databases. The key words used were: *ultrasound*, *sonography*, *imaging techniques*, *ultrasonography*, *interventional ultrasonography*, *plantar fascia* and *plantar fasciitis*. The literature search yielded 34 relevant studies. Sixteen studies evaluated the effect of different interventions on PF thickness in patients with PFS using US; 12 studies compared PF thickness between patients with and without PFS using US; 6 studies investigated the application of US as a guide for therapeutic intervention in patients with PFS. There were variations among studies in terms of methodology used. The results indicated that US can be considered a reliable imaging technique for assessing PF thickness, monitoring the effect of different interventions and guiding therapeutic interventions in patients with PFS. (E-mail: mnakhaee@gmail.com)

Key Words: **Ultrasound, Plantar fascia, Plantar fasciitis, Systematic, Review.**

INTRODUCTION

Plantar fascia (PF) is a thickened fibrous sheet of connective tissue that originates from the medial tubercle of the calcaneus and attaches to the plantar surface of the metatarsophalangeal joints. It acts as a static and dynamic stabilizer of the longitudinal arch of the foot and as a dynamic shock absorber (Hamblen and Simpson 2010; Oatis 2009). Plantar fasciitis (PFS) is the most common type of PF injury, estimated to affect 10% of the general population during middle age (Gordon et al. 2012; Urse 2012); also 8% of foot injuries in runners are related to PFS (Landorf et al. 2006). The main symptom of PFS is morning pain or pain at the beginning of activity after rest (Ragab and Othman 2012), which may be worsen by the end of the day (Landorf et al. 2006). Some studies have reported PFS is an inflammatory condition (Yucel et al. 2009), and some researchers have reported the hyaline degeneration of PF in PFS (Thomas et al. 2010). The risk factors include biomechanical factors (*e.g.*, excessive pronation, reduced ankle dorsiflexion), improper footwear, obesity and extensive standing, walking, and running (Gordon et al. 2012; Landorf et al. 2006; Thomas et al. 2010).

An appropriate physical examination is the main method for evaluating patients with PFS. Tenderness and pain may be increased by passive dorsiflexion of the toes or by having the patient stand on the tips of the toes. Tightness of the calf muscles, limited dorsiflexion of the ankle and tightness of the PF that restricts extension of the toes are other findings in the physical examination (Buchbinder 2004; Thomas et al. 2010; Young et al. 2001).

Radiographic studies, as an objective method, play an important role in evaluation of PF in patients with and without PFS (Fabrikant and Park 2011). For this

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purpose, the imaging techniques available are plain radiography, bone scan, magnetic resonance imaging (MRI) and ultrasound (US) (McMillan et al. 2009). Direct imaging of the PF is possible with MRI and US (McMillan et al. 2009). These methods have revealed that PF is thicker in patients with PFS than in those without PFS (Cheng et al. 2012; Wu et al. 2011). Therefore, the changes in PF thickness after interventions in patients with PFS are measurable with imaging techniques. The advantages of US as compared with MRI are that it is non-invasive, it is radiation free, it is a cost-effective approach that is also well tolerated by patients and it is appropriate for serial follow-up (Fabrikant and Park 2011).

Real-time US guidance is used to enhance the accuracy of such interventions as injections and extracorporeal shock wave therapy (ESWT) (Gordon et al. 2012; Kayhan et al. 2011; McMillan et al. 2012). Injections made under US guidance can eliminate the risk of injection into the fat pad and thus prevent atrophy of the fat tissue, which in turn results in a reduced number of injections (Tsai et al. 2006).

Many studies have investigated PF thickness in different patients and in different conditions using objective techniques. Real-time US imaging is one of the objective tools commonly used in the assessment of PF in many studies. The purpose of this study was to systematically review the previously published studies carried out on the merit of US in the assessment of PF and diagnosis of PFS and as a guide for therapeutic intervention in patients with PFS, with particular attention to its clinical application.

METHODS

A systematic review was conducted for the period 2000 to 2012 using the following databases: Medline, CINAHL, Embase, Science Direct, Scopus, PubMed, Springer. The guideline of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) was used (Liberati et al. 2009).

Search strategy

The key words used were: *ultrasound*, *sonography*, *imaging techniques*, *ultrasonography*, *interventional ultrasonography*, *plantar fascia* and *plantar fasciitis*. In addition, reference lists of the articles were also checked.

Inclusion criteria

The articles were included if they have met the following criteria: (i) the studies were carried out patients with PFS or healthy patients; (ii) US was applied in the assessment of PF; (iii) PF thickness was evaluated; (iv) the studies were published in the English language.

Study selection

Titles and abstracts were evaluated first by two reviewers; if the abstract or title was not clear, the entire article was checked. Articles were selected on the basis of the Critical Appraisal Skills Programme (CASP, CASP UK, Oxford, UK) checklist. The CASP results are summarized Table 1. The third and fourth reviewers separately read a random sample of the articles. If there was no consensus, a consensus meeting was arranged to make the final decision.

The outcome of a study was identified as “positive” if the authors concluded that the US imaging can be used as an appropriate method for the assessment, diagnosis and as a therapeutic guide for intervention in patients with PFs. The outcome of a study was identified as “negative” if the authors concluded that the US imaging cannot be used as an appropriate method for the assessment, diagnosis and as a therapeutic guide for intervention in patients with PFs.

Data collection process

One hundred twenty-eight articles were identified by the search process. Thirty-four studies were relevant and included in this review. Sixteen of the 34 studies evaluated the effects of different interventions in patients with PFS using US imaging. In 12 studies the role of US in identifying changes in PF thickness in patients with PFS was compared with that in l patients without PFS. In 6 of the 34 studies, US was used as a guide for therapeutic interventions (Fig.1).

RESULTS

Using the appropriate key words, 128 articles were identified by the database searching process; of these, 34 (Abdel-Wahab et al. 2008; Akfirat et al. 2003; Buchbinder et al. 2002; Cheng et al. 2012; Fabrikant and Park 2011; Folman et al. 2005; Genc et al. 2005; Gordon et al. 2012; Hammer et al. 2005; Huang et al. 2010; Hyer et al. 2005; Kamel and Kotob 2000; Kane et al. 2001; Kapoor et al. 2010; Karabay et al. 2007; Kayhan et al. 2011; Kiritsi et al. 2010; Mahowald et al. 2011; McMillan et al. 2012; Ozdemir et al. 2005; Ragab and Othman 2012; Ryan et al. 2009; Saber et al. 2012; Sabir et al. 2005; Theodore et al. 2004; Tsai et al. 2000a, 2000b, 2006; Vohra and Japour 2009; Vohra et al. 2002; Walther et al. 2004; Wearing et al. 2007; Wu et al. 2011; Yucel et al. 2009) studies were relevant and included in this review. Table 2 provides details on the studies investigating PFS using US from 2000 to 2012.

Sixteen of the 34 relevant studies (Fabrikant and Park 2011; Genc et al. 2005; Gordon et al. 2012; Hammer et al. 2005; Huang et al. 2010; Kamel and

Table 1. Critical Appraisal Skills Programme results

	Kamel and Kotob (2000)	Tsai et al. (2000a)	Tsai et al. (2000b)	Kane et al. (2001)	Buchbinder et al. (2002)	Vohra et al. (2002)	Akfirat et al. (2003)	Theodore et al. (2004)	Walther et al. (2004)	Folman et al. (2005)	Genc et al. (2005)	Hammer et al. (2005)	Hyer et al. (2005)	Ozdemir et al. (2005)	Sabir et al. (2005)	Tsai et al. (2006)	Karabay et al. (2007)
Clearly focused question	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Appropriate design	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Appropriate recruitment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Matched control	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes
Test procedure clearly described	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Appropriate outcomes used	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Outcome accurately measured to minimize bias	No	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No	No	No	Yes	Yes	No
Confounding factors accounted	No	Yes	Yes	No	Yes	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No	No
Appropriate analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precise statistical results presented	No	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ability to generalize results	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes
Interpretation related to the existing evidence	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total score	9	10	12	10	12	9	8	11	6	8	12	8	8	10	12	10	9

Table 1. Continued

	Wearing et al. (2007)	Abdel-Wahab et al. (2008)	Ryan et al. (2009)	Vohra and Japour (2009)	Yucel et al. (2009)	Huang et al. (2010)	Kiritsi et al. (2010)	Kapoor et al. (2010)	Fabrikant and Park (2011)	Kayhan et al. (2011)	Mahowald et al. (2011)	Wu et al. (2011)	Cheng et al. (2012)	Gordon et al. (2012)	McMillan et al. (2012)	Ragab and Othman (2012)	Saber et al. (2012)
Clearly focused question	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Appropriate design	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Appropriate recruitment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Matched control	Yes	Yes	No	No	No	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	No
Test procedure clearly described	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Appropriate outcomes used	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Outcome accurately measured to minimize bias	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	No
Confounding factors accounted	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	No
Appropriate analysis	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precise statistical results presented	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Ability to generalize results	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	No
Interpretation related to the existing evidence	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total score	10	11	7	6	11	12	11	9	11	10	7	9	11	7	12	9	7

Table 2. Details of studies carried on the evaluation of PF thickness under different conditions using US

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	US machine	Position for assessment	Alignment	Measurement station	Conclusion
Kamel and Kotob (2000)	20 P 20 H	To investigate value of US in diagnosis of PFS and changes in PF after US-guided local injection	PF thickness	US	11-MHz linear array transducer	Sony ATL Apogee 800	NA	NA	NA	US procedure should be considered early in diagnosis and management of heel pain. US-guided local injection proved to be tolerable and effective in treatment of PFS.
Tsai et al. (2000b)	14 P	To investigate efficacy of US-guided injection for treatment of proximal PFS and to evaluate mechanical properties of heel pad after injection	PF thickness Heel pad thickness Pain	US TT VAS	10-MHz linear array transducer	GE LOGIQ 700 MR	Prone with feet hanging over edge of table; real-time scanning occasionally performed during dynamic dorsiflexion of toes to stretch PF and to allow easier delineation of its margins	Longitudinal	Proximal end near its insertion into calcaneus	US provides objective measurement of therapeutic effect on proximal PFS. Accurate injection under US guidance can effectively treat proximal PFS without significant deterioration of mechanical properties of heel pads.
Tsai et al. (2000a)	102 P 33 H	To investigate US features of PFS	PF thickness Heel pad thickness	US	12-MHz linear array transducer	Philips ATL HDI 5000	Prone with feet hanging over edge of table; real-time scanning occasionally performed during dynamic dorsiflexion of toes to stretch PF and to allow easier delineation of its margins.	Longitudinal	Proximal end near its insertion into calcaneus	Increased thickness and hypo-echoic PF are consistent with US findings in patients exhibiting PFS.
Kane et al. (2001)	23 P (28 F)	To compare US with bone scintigraphy in diagnosis of PFS and to compare US-guided injection with PG injection in management of idiopathic PFS	Pain PF thickness	VAS HTI US	7.5-MHz linear array transducer	Siemens Acuson	NR	Longitudinal (accurate positioning of transducer was confirmed on transverse view of heel)	From anterior edge of inferior calcaneal border to inferior border of US abnormality	US and bone scintigraphy are equally effective in diagnosis of PFS. US-guided injection is effective in management of PFS, but is not more effective than PG injection. US may be used as objective measure of response to treatment in PFS.
Buchbinder et al. (2002)	178 P	To determine whether US-guided ESWT reduces pain and improves function in patients with PFS	Pain Function Quality of life	VAS Maryland foot score Walking ability SF36 score Problem elicitation technique score	NR	Dornier Epos Ultra (ESWT Company LLC)	Sitting in chair with affected foot resting on foam support and footstool	NR	Water cushion and transducer placed over heel and positioned so that origin of PF adjacent to calcaneum was visible	There was no evidence to support beneficial effect on pain, function and quality of life of US-guided ESWT over placebo in patients with US-proven PFS.

Vohra et al. (2002)	109 p	To evaluate thickness of medial, central and lateral bands of PF using US techniques	PF thickness	US	7-MHz linear array transducer	Accustom 128 XT	Supine with feet hanging over edge of table, with dorsiflexion of toes to stretch PF to delineate its margins	Longitudinal	Point nearest calcaneal insertion of PF	There were significant differences in thickness of three PF bands in symptomatic patients. PF index (ratio of mean thickness of symptomatic medial, central and lateral PF bands to that of asymptomatic bands) was established.
Akfirat et al. (2003)	40 P	To study high-frequency sonographic in examination of PFS	PF thickness	US Radiography MRI	7.5-MHz linear array transducer	GE LOGIQ 200 Pro series	Prone with free ankle motion to examine PF easily	Longitudinal	Insertion of calcaneus as bone landmark	US should be considered early in management of PF and could be used as initial imaging modality for investigation of patients with PFS.
Theodore et al. (2004)	150 P	To assess clinical safety and effectiveness of US-guided ESWT for treatment of PFS	Pain	VAS	NR	Dornier Epos Ultra	Position of shock wave source was modified during treatment using US image and patient feedback to ensure that shock wave was focused precisely into pain epicenter	NR	NR	US-guided ESWT represents tolerable treatment option for chronic proximal PFS.
Walther et al. (2004)	20 P 20 H	To characterize PDU findings in PFS	Pain Moderate or marked hyperemia	VAS PDU US	7.5-MHz linear array transducer	Siemens	Prone with feet hanging freely over table	Longitudinal view (accurate positioning of transducer was confirmed on transverse view of heel)	PF, to visualize the first 3 cm PF from its insertion into calcaneus its proximal end near its insertion into calcaneus	PDU improves value of US as non-invasive technique for diagnosis of PFS, providing additional information on local hyperemia.
Folman et al. (2005)	32 P	To assess US-guided needle fasciotomy	Pain	VAS	10-MHz linear array transducer	NR	NR	NR	NR	US-guided needle fasciotomy is tolerable and effective method for relief of conservatively unmanageable heel pain caused by PFS.
Genc et al. (2005)	30 P 30 H	To evaluate long-term efficacy of injection for PFS using clinical parameters and high-resolution US	PF thickness Pain	US VAS	7.5-MHz linear array transducer	Hitachi EUB 420	NR	Longitudinal (accurate positioning of transducer was confirmed on transverse view of heel)	From anterior edge of inferior calcaneal border to inferior border of US abnormality	Significant improvements were observed in PF thickness, hypo-echogenicity of fascia and VAS values at long-term US follow-up of PFS patients treated with steroid injection.
Hammer et al. (2005)	22 P	To investigate effect of ESWT on US appearance of chronically painful, proximal PFS	PF thickness Pain Walking time	US VAS Time recorder	NR	Piezoson 300	Prone with feet hanging freely over table	Longitudinal	Thickness of PF was measured about 2 cm distal of medial calcaneal tuberosity	After ESWT, US appearance of thickness of PF in patients with PFS decreased, and pain and walking time improved.

(*Continued*)

Table 2. (*Continued*)

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	US machine	Position for assessment	Alignment	Measurement station	Conclusion
Hyer et al. (2005)	30 P (39 F)	To determine success of US-guided ESWT for treatment of recalcitrant PFS	Pain	VAS	NR	Dornier Epos Ultra	NR	Longitudinal	Point of maximal tenderness; US screen was used to visualize PF and plantar cortex of calcaneus	These early results indicate US-guided ESWT may be useful in treatment of chronic PFS.
Ozdemir et al. (2005)	39 P 22 H	To investigate role of US in diagnosis of PFS	PF thickness	US	7.5-MHz linear array transducer	GE LOGIQ Pro 200	Prone, with full knee extension and 90° dorsiflexion of ankle	Longitudinal	5 mm distal to calcaneal insertion of plantar aponeurosis	US may detect relatively small differences in PF thickness, even in clinically unequivocal PFS.
Sabir et al. (2005)	77 P	To investigate efficacy of US in detection of PFS compared with MRI findings in patients with inferior heel pain	PF thickness Heel pad thickness	US MRI	6.0- to 9.0-MHz linear array transducer	LOGIQ Pro 500	Prone position, with full knee extension and 90° dorsiflexion of ankle	Longitudinal	PF crosses anterior aspect of inferior border of calcaneus	Although MRI is modality of choice in morphologic assessment of different PF lesions, US can also serve as effective tool and may substitute for MRI in diagnosis of PF.
Tsai et al. (2006)	25 P	To compare effectiveness of US-guided and PG injection for treatment of proximal PFS	Pain intensity Thickness Echogenicity of proximal PF	TT VAS US	5- to 12-MHz linear array transducer	Philips HDI 5000 scanner	Prone, with full knee extension and 90° dorsiflexion of ankle; real-time scanning during dynamic dorsiflexion of toes	Longitudinal	Proximal end of PF, near its insertion into calcaneus	Injection can be effective way to treat PFS, and injection under US guidance is associated with lower recurrence of heel pain.
Karabay et al. (2007)	23 P 23 H	To evaluate patients with PFS via US compared with their asymptomatic feet and control group of 23 people	PF thickness Heel pad thickness	US	7.5- to 9-MHz linear array transducer	Siemens Sonoline Sienna	NR	NR	PF proximal end near its insertion into calcaneus (1 cm away from insertion point to bone)	US seem to be valuable, non-invasive diagnostic tool for evaluation of PFS.
Wearing et al. (2007)	10 P 10 H	To compare US measures of PF thickness and radiographic measures of arch shape and regional loading of foot during gait in individuals with and without unilateral PFS	Pain PF thickness Static arch H angle	VAS US Pressure plate	5- to 12-MHz linear array transducer	HDI 5000	Prone with ankle in neutral (0° of dorsiflexion and plantar flexion)	Longitudinal	5 mm from insertion, at anterior aspect of inferior border of calcaneus	PF thickness and pain in PFS are associated with regional loading and static shape of arch.
Abdel-Wahab et al. (2008)	17 P (23 F) 11 H (22 F)	To compare high-resolution US with MRI to assess its value as alternative modality to confirm clinical diagnosis of PFS	PF thickness Abnormal signal Subcutaneous edema Fluid collection Fiber rupture Calcaneal spur	US MRI	5- to 17-MHz linear array transducer and 1.5-T magnet	Philips iU22 Siemens Avanto	Prone with feet dorsiflexed and hanging over edge of table	Longitudinal	Calcaneal insertion	Sonographic diagnosis of PFS is useful tool with acceptable diagnostic accuracy comparable to that of MRI.
Ryan et al. (2009)	20 P	To report on effectiveness of US-guided injections in reducing pain associated with chronic PFS	Pain	VAS	5- to 12-MHz and 7- to 15-MHz linear array high-resolution transducer	Philips HDL 5000	Prone position	Longitudinal and transverse	NR	US-guided injections elicited good clinical response in patients with chronic PFS insofar as pain was reduced during rest and activity.

Vohra and Japour (2009)	41 P (46 F)	To offer surgeon clear visualization of anatomy at surgical site with US-guided PF release.	Function	AOFAS hindfoot rating scale	7-MHz linear array transducer	Accustom 128 XT	Supine with feet hanging over edge of table, with dorsiflexion of toes to stretch PF to delineate its margins	Longitudinal	Point nearest calcaneal insertion of PF	US-guided PF release technique is practical surgical procedure for relief of chronic PFS.
Yucel et al. (2009)	27 P (35 F)	To compare efficacy of US-guided and PG injections in PFS	Pain PF thickness Fat pad thickness	VAS US	NR	NR	Prone with free ankle motion, to allow easy examination of PF	Longitudinal	Point nearest calcaneal insertion of the PF	US-guided, PG and SG injections were effective in conservative treatment of PFS.
Huang et al. (2010)	50 P	To evaluate effectiveness of US-guided injections in patients with unilateral PFS	Pain PF thickness Fat pad thickness Maximal center of pressure velocity during first-step loading response	VAS US Gait assessment	10-MHz linear array transducer	GE LOGIQ Book	Prone with feet hanging over edge of table	Longitudinal	Point nearest calcaneal insertion of PF	US-guided injection is effective in treatment of foot pain associated with PFS and increases center of pressure velocity during loading response without inducing fat pad atrophy.
Kiritsi et al. (2010)	30 P	To investigate effect of LLLT on PFS	PF thickness Pain	US VAS	7.5-MHz linear array transducer	NR	Prone with feet hanging over edge of table.	Longitudinal	PF crossed anterior aspect of inferior border of calcaneus	US imaging is able to depict morphologic changes related to PFS. Infrared laser may contribute to healing and pain reduction in PFS.
Kapoor et al. (2010)	25 P	To evaluate and compare roles of elastography, US and MRI in patients with PFS	Echogenicity Margins PF thickness	US MRI	9-MHz linear array transducer	Acuson 2000, 1.5-T system Siemens Maestro class	Prone	Longitudinal	NR	Combination of elastography and US improves accuracy from 68% to 96% and also stages extent of disease, with results being comparable to those for MRI.
Fabrikant and Park (2011)	30 P	To study effectiveness of injection and biomechanical correction for PFS	PF thickness	US	8-MHz linear array transducer	Siemens Sonoline Sienna	Sitting with feet over edge of table and allowed to see examination results; foot was allowed to relax in semiflexed position, and PF was traced by hand from the arch into the heel to discern borders	Longitudinal	PF portion from base of medial calcaneal tubercle where a bright echogenic line was easily visible	Office-based US can help diagnose and confirm PFS through measurement of PF thickness.
Kayhan et al. (2011)	31 P	To investigate effect of US-guided injection on clinical and radiologic responses in patients with proximal PFS	PF thickness Fat pad thickness Fascial echogenicity Perifascial edema Function Alignment Pain	US AOFAS midfoot scale	10- to 5-MHz linear array transducer	Acuson X300	Prone with feet hanging over edge of table, with dorsiflexion of toes to stretch PF to delineate its margins	Longitudinal	10–15 mm from insertion of calcaneus	US-guided injection enables real-time imaging of PF during needle insertion.

(*Continued*)

Table 2. (*Continued*)

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	US machine	Position for assessment	Alignment	Measurement station	Conclusion
Mahowald et al. (2011)	30 P (39 F)	To determine changes in PF thickness as reliable gauge of efficacy of various treatment protocols for PFS	PF thickness Pain	US VAS	7.5-MHz linear array transducer	NR	NR	Longitudinal	Tip of plantar medial tuberosity of calcaneus to superficial aspect of PF	Use of US to record changing thickness of PF is valid objective measurement to assess effectiveness of new or existing treatment protocols.
Wu et al. (2011)	13 P 40 H	To compare stiffness of PF using US in healthy patients of different ages, as well as patients with PFS	PF thickness PF stiffness	US	6- to 12-MHz linear array transducer	Acuson S2000	Prone with 90° of knee flexion in the neutral ankle position	Longitudinal	Anterior edge of inferior calcaneal border vertically to inferior border of PF	US revealed that PF softens with age and in patients with PFS.
Cheng et al. (2012)	11 P (20 F) 26 H (52 F)	To evaluate intra- and inter-rater reliability of US measurements of thickness and echogenicity of PF	PF thickness	US	5- to 12-MHz linear array transducer	Philips HD3	Prone with feet hanging freely over table	Longitudinal and transverse planes	Thickest part of PF at its insertion onto calcaneal bone	Reliability of US examination of PF thickness is high. Longitudinal instead of transverse scanning is recommended for imaging PF.
Gordon et al. (2012)	25 P (35 F)	To determine long-term effectiveness of EPAT for treatment of PFS	Pain PF thickness	RPS US	L12/5 probe	Phillips HD II	Prone with feet hanging freely over table	Longitudinal	1 cm distal to origin on medial tubercle	For patients with >12-mo history of heel pain, EPAT can effectively decrease PF thickness as indicated objectively by US evaluation and reduce patient-reported pain.
McMillan et al. (2012)	82 P	To investigate effectiveness of US-guided injection in treatment of PFS	Pain PF thickness	FSHQ US	NR	NR	NR	NR	NR	Single US-guided injection is tolerable and effective short-term treatment for PFS.
Ragab and Othman (2012)	25 P	To study effectiveness of PRP treatment for chronic PFS	Pain PF thickness	VAS US	7.5-MHz linear array transducer	NR	Prone with feet hanging free over end of table	Longitudinal	Anterior aspect of inferior border of calcaneus	US reveals significant changes in thickness and signal intensity of PF after PRP injection. Injection of PRP is tolerable and does not affect biomechanical.
Saber et al. (2012)	60 P	To evaluate and compare therapeutic effectiveness of US-guided local steroid injection with ESWT in PF thickness	Pain (its impact on functional status, footwear requirement and effect on gait) PF thickness	Mayo clinical scoring system US	NR	NR	In base of medial calcaneal tubercle, where a bright echogenic line was easily visible	Longitudinal	Lateral recumbent position with affected side down	US-guided local steroid injection and ESWT proved effective in treatment of PFS. Both groups had significant clinical and US-documented improvement of their disease after therapy.

PF = plantar fascia; PFS = plantar fasciitis; US = ultrasonography; P = patients; H = healthy patients; F = feet; TT = tenderness threshold; VAS = visual analogue scale; HTI = heel tenderness index; ESWT = extracorporeal shock wave therapy; SF = The Short Form (36) Health Survey; PDU = Power Doppler ultrasonographic; MRI = magnetic resonance imaging; BMI = body mass index; AOFAS = American Orthopaedic Foot and Ankle Society; PG = palpation-guided; SG = scintigraphy-guided; LLLT = low-level laser therapy; VI = vascular index; EPAT = extracorporeal pulse-activated therapy; RPS = rated pain score; FSHQ = Foot Health Status Questionnaire; PRP = platelet-rich plasma; NA = not available; NR = not reported.

Kotob 2000; Kane et al. 2001; Kayhan et al. 2011; Kiritsi et al. 2010; Mahowald et al. 2011; McMillan et al. 2012; Ragab and Othman 2012; Saber et al. 2012; Tsai et al. 2000b, 2006; Yucel et al. 2009) evaluated the effects of different interventions on PF thickness in patients with PFS using US imaging. Table 3 provides details on the studies evaluating different interventions in patients with PFS using US. As outlined in Table 3, in 9 of 16 studies, US was used as both a guide for therapeutic intervention and an assessment tool for evaluating PF thickness in patients with PFS. In the remaining 7studies, US was used as a tool for assessing PF thickness for evaluating the effects of interventions in patients with PFS only.

Twelve of 34 studies (Abdel-Wahab et al. 2008; Akfirat et al. 2003; Cheng et al. 2012; Kapoor et al. 2010; Karabay et al. 2007; Ozdemir et al. 2005; Sabir et al. 2005; Tsai et al. 2000a; Vohra et al. 2002; Walther et al. 2004; Wearing et al. 2007; Wu et al. 2011) investigated the role of US in identifying changes in PF thickness in patients with PFS as compared with patients without PFS. Details of studies are provided in Table 4. As seen in Table 4, in 4 of 12 studies, US was compared with other imaging methods for the evaluation of PF in patients with and without PFS. In 8 studies, US was just used as a tool for assessing PF thickness in patients with and without PFS and diagnosing PFS.

In 6 of the 34 studies (Buchbinder et al. 2002; Folman et al. 2005; Hyer et al. 2005; Ryan et al. 2009; Theodore et al. 2004; Vohra and Japour 2009), US was used as a guide for therapeutic interventions. Details of these studies are provided in Table 5. In 3 of these 6 studies, the effects of US guidance of ESWT were assessed; in 2 studies, US was used as a guide for surgery; and in one study, the effectiveness of US-guided injections was reported.

DISCUSSION

The purpose of this study was to systematically review published studies conducted in the assessment of PF in patients with and without PFS using US for the period 2000 to 2012. Thirty-four studies, carried out to assess PF thickness, monitor the effect of different interventions and guide therapeutic interventions in patients with PFS were reviewed. According to the results of this review, adequate evidence exists that ultrasound is a useful, reliable, less expensive, easier, faster and non-invasive imaging tool for assessing PF.

In all reviewed studies, the authors reported positive results in favor of US imaging in the assessment of PF thickness. There were many methodologic differences among studies. The most important variations were in sample size, duration of symptoms, inclusion criteria, types of US equipment, interventions used, measurement methods and follow-up duration. However, the results of this review support the use of US imaging in the assessment of PF thickness.

Evaluating PF thickness after different interventions

As indicated in Table 3, 16 studies evaluated the use of US in different interventions such as injection, ESWT, low-level laser therapy (LLLT) and extracorporeal pulse-activated therapy (EPAT) in patients with PFS.

Six of 16 studies (Huang et al. 2010; Kamel and Kotob 2000; Kayhan et al. 2011; McMillan et al. 2012; Saber et al. 2012; Tsai et al. 2000b) investigated the effect US-guided therapeutic injections in patients with PFS. All 6 studies reported a positive effect of the use of US for guided injection and evaluation of PF thickness before and after treatment. For example, in a randomized, double-blinded, placebo-controlled trial, McMillan et al. (2012) investigated the effectiveness of US-guided injection in the treatment of PFS in 82 patients. The primary outcomes measured were pain and PF thickness 4, 8 and 12 wk after injection. The authors concluded that a single US-guided injection is a tolerable and effective short-term treatment for PFS and provides greater pain relief than placebo at 4 wk and reduces abnormal swelling of the PF for up to 3 mo.

Huang et al. (2010) evaluated the effectiveness of US-guided injections into the PF to reduce pain and improve gait in patients with unilateral PFS. Fifty patients with chronic unilateral PFS were recruited and divided into an experimental group and a control group. Pain and PF thickness in the symptomatic foot significantly decreased, as noted at the 3-wk and 3-mo follow-up examinations after injection. However, fat pad thickness remained unchanged. The center of pressure velocity during the loading response without inducing fat pad atrophy increased 3 mo after injection in the experimental group.

According to the results of the aforementioned studies, it seems that US-guided injection is an accurate and tolerable technique for treating PFS and plays a role in reducing PF thickness, risk of PF rupture and fat pad atrophy. Also, as an objective method, US can be used to evaluate PF thickness changes after different interventions.

In three studies (Kane et al. 2001; Tsai et al. 2006; Yucel et al. 2009), US-guided injection was compared with palpation-guided injection in the evaluation of PF thickness in patients with PFS. For example, Yucel et al. (2009) compared the efficacy of injections guided by scintigraphy, US and palpation in 27 patients with PFS. Patients were evaluated for pain intensity before the injections and at the last follow-up at 25.3 mo. There were significant improvements in PF thickness, fat pad

Table 3. Details of studies evaluating different interventions in patients with PFS using US

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	Type of US	Position for assessment	Alignment	Measurement station	Conclusion
Kamel and Kotob (2000)	20 P 20 H	To investigate value of US in diagnosis of PFS and changes in PF after US-guided local injection	PF thickness	US	11-MHz linear array transducer	ATL Apogee 800	NA	NA	NA	US procedure should be considered early in diagnosis and management of heel pain. US-guided local injection proved to be tolerable and effective in treatment of PFS.
Tsai et al. (2000b)	14 P	To investigate efficacy of US-guided injection for treatment of proximal PFS and to evaluate mechanical properties of heel pad after injection	PF thickness Heel pad thickness Pain	US TT VAS	10-MHz linear array transducer	GE LOGIQ 700 MR	Prone with feet hanging over edge of table; real-time scanning occasionally performed during dynamic dorsiflexion of toes to stretch the PF and allow easier delineation of its margins	Longitudinal	PF measured at its proximal end near its insertion into calcaneus	US provides objective measurement of therapeutic effect on proximal PFS. Accurate injection under US guidance can effectively treat proximal PFS without significant deterioration of mechanical properties of heel pads.
Kane et al. (2001)	23 P (28 F)	To compare US with bone scintigraphy in diagnosis of PFS and to compare US-guided injection with PG injection in management of idiopathic PFS	Pain PF thickness	VAS HTI US	7.5-MHz linear array transducer	Acuson	NR	Longitudinal (accurate positioning of transducer confirmed on transverse view of heel)	From anterior edge of inferior calcaneal border to inferior border of US abnormality	US and bone scintigraphy are equally effective in diagnosis of PFS. US-guided injection is effective in management of PFS, but is not more effective than PG injection. US may be used as objective measure of response to treatment in PFS.
Genc et al. (2005)	30 P 30 H	To evaluate long-term efficacy of injection for PFS using clinical parameters and high-resolution US	PF thickness Pain	US VAS	7.5-MHz linear array transducer	Hitachi EUB 420	NR	Longitudinal (accurate positioning of transducer confirmed on transverse view of heel)	From anterior edge of inferior calcaneal border to inferior border of US abnormality	Significant improvements were observed in PF thickness, hypo-echogenicity of fascia and VAS values at long-term US follow-up of PFS patients treated with steroid injection.
Hammer et al. (2005)	22 P	To investigate effect of ESWT on US appearance of chronically painful, proximal PFS	PF thickness Pain Walking time	US VAS Time recorder	NR	Piezoson 300	Prone with feet hanging freely over table	Longitudinal	Thickness of PF measured about 2 cm distal of the medial calcaneal tuberosity	After ESWT, US revealed thickness of PF in patients with PFS decreased; pain and walking time improved.
Tsai et al. (2006)	25 P	To compare effectiveness of US-guided and PG injections for treatment of proximal PFS	Pain intensity Thickness and echogenicity of proximal PF	TT VAS US	5- to 12-MHz linear array transducer	Philips HDI 5000 scanner	Prone, full knee extension and 90° dorsiflexion of ankle; real-time scanning during dynamic dorsiflexion of toes	Longitudinal	Proximal end of PF, near its insertion into calcaneus	Injection can be effective way to treat PFS, and injection under US guidance is associated with lower recurrence of heel pain.
Yucel et al. (2009)	27 P (35 F)	To compare efficacy of US-guided and PG injections in PFS	Pain PF thickness Fat pad thickness	VAS US	NR	NR	Prone position during examination, and ankle motion was free, so as to allow easy examination of PF	Longitudinal	Point nearest calcaneal insertion of PF	US-guided, PG and SG injections were effective in conservative treatment of PFS.

Huang et al. (2010)	50 P	To evaluate effectiveness of US-guided injections in patients with unilateral PFS	Pain PF thickness Fat pad thickness Maximal center of pressure velocity during first-step loading response	VAS US Gait assessment	10-MHz linear array transducer	GE LOGIQ Book	Prone with feet hanging over edge of table	Longitudinal	Point nearest calcaneal insertion of PF	US-guided injection is effective in treatment of foot pain associated with PFS and increases the center of pressure velocity during loading response without inducing fat pad atrophy.
Kiritsi et al. (2010)	30 P	To investigate effect of LLLT on PFS	PF thickness Pain	US VAS	7.5-MHz linear array transducer	NR	Prone with feet hanging over edge of table	Longitudinal	PF crossed anterior aspect of inferior border of calcaneus	US imaging is able to depict morphologic changes related to PFS. Infrared laser may contribute to healing and pain reduction in PFS.
Fabrikant and Park (2011)	30 P	To study effectiveness of injection and biomechanical correction for PFS	PF thickness	US	8-MHz linear array transducer	Siemens Sonoline Sienna	Sitting with feet over edge of table and allowed to see examination results; foot allowed to relax in semiflexed position; PF traced by hand from arch into heel to discern borders	Longitudinal	PF portion from base of medial calcaneal tubercle, where a bright echogenic line was easily visible	Office-based US can help diagnose and confirm PFS through measurement of PF thickness.
Kayhan et al. (2011)	31 P	To investigate effect of US-guided injection on clinical and radiologic responses in patients with proximal PFS	PF thickness Fat pad thickness Fascial echogenicity Perifascial edema Function Alignment Pain	US AOFAS midfoot scale	10- to 5-MHz linear array transducer	Accuson X300	Prone with feet hanging over edge of table, with dorsiflexion of toes to stretch PF to delineate its margins	Longitudinal	10–15 mm from insertion of calcaneus	US-guided injection enables real-time imaging of PF during needle insertion.
Mahowald et al. (2011)	30 P (39 F)	To determine changes in PF thickness as a reliable gauge of efficacy of various treatment protocols for PFS	PF thickness Pain	US VAS	7.5-MHz linear array transducer	NR	NR	Longitudinal	Tip of plantar medial tuberosity of calcaneus to superficial aspect of PF	Use of US to record changing thickness of PF is valid objective measurement to assess effectiveness of new or existing treatment protocols.
Gordon et al. (2012)	25 P (35 F)	To determine long-term effectiveness of EPAT for treatment of PFS	Pain PF thickness	RPS US	L12/5 probe	Phillips HD II	Prone with feet hanging freely over table	Longitudinal	1 cm distal to origin on medial tubercle	For patients with >12-mo history of heel pain, EPAT can effectively decrease PF thickness as indicated objectively by US evaluation and reduce patient-reported pain.
McMillan et al. (2012)	82 P	To investigate effectiveness of US-guided injection in treatment of PFS	Pain PF thickness	FSHQ US	NR	NR	NR	NR	NR	Single US-guided injection is tolerable and effective short-term treatment for PFS.
Ragab and Othman (2012)	25 P	To study effectiveness of PRP treatment for chronic PFS	Pain PF thickness	VAS US	7.5-MHz linear array transducer	NR	Prone with feet hanging free over end of table	Longitudinal	Anterior aspect of inferior border of calcaneus	US reveals significant changes in thickness and signal intensity of PF after PRP injection. Injection of PRP is tolerable and does not affect biomechanical function of foot.

(Continued)

Table 3. (*Continued*)

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	Type of US	Position for assessment	Alignment	Measurement station	Conclusion
Saber et al. (2012)	60 P	To evaluate and compare therapeutic effectiveness of US-guided local steroid injection and ESWT in PF thickness	Pain (its impact on functional status, footwear requirement and effect on gait) PF thickness	Mayo clinical scoring system US	NR	NR	In base of medial calcaneal tubercle, where a bright echogenic line was easily visible	Longitudinal	Lateral recumbent position with affected side down	US-guided local steroid injection and ESWT proved effective in treatment of PFS. Both groups had significant clinical and US-documented improvement of their disease after therapy.

PF = plantar fascia; PFS = plantar fasciitis; US = ultrasonography; P = patients; H = healthy patients; F = feet; TT = tenderness threshold; VAS = visual analogue scale; HTI = heel tenderness index; ESWT = extracorporeal shock wave therapy; PDU = Power Doppler ultrasonographic; MRI = magnetic resonance imaging; BMI = body mass index; AOFAS = American Orthopaedic Foot and Ankle Society; PG = palpation-guided; SG = scintigraphy-guided; LLLT = low-level laser therapy; VI = vascular index; EPAT = extracorporeal pulse-activated therapy; RPS = rated pain score; FSHQ = Foot Health Status Questionnaire; PRP = platelet-rich plasma; NA = not available; NR = not reported.

thickness and pain intensity (on the visual analogue scale). Because of the increased accuracy and reduced repetition of injections, they suggested that injections should preferably be performed with US guidance.

The remaining 7 of the 16 studies (Fabrikant and Park 2011; Genc et al. 2005; Gordon et al. 2012; Hammer et al. 2005; Kiritsi et al. 2010; Mahowald et al. 2011; Ragab and Othman 2012) investigated the efficacy of different interventions on PF thickness. Kiritsi et al. (2010) and documented the effect of LLLT on PFS using the US appearance of the aponeurosis and pain scores. Gordon et al. (2012) and Hammer et al. (2005) used US measurement of PF as an objective tool for evaluating shock wave therapy. Long-term US follow-up to evaluate the effect of injection on PF thickness in patients with PFS was performed by Genc et al. (2005) and Ragab and Othman (2012). Also, Fabrikant and Park (2011) and Mahowald et al. (2011) used US to monitor PF thickness as a reliable measure in diagnosing and assessing the effect of different treatments in patients with PFS.

Despite differences in study sample sizes and selected interventions, all studies were classified as positive. The results indicate that US is clinically and objectively able to evaluate PF thickness in patients with PFS and to depict the morphologic changes related to PFS.

Diagnosis of plantar fasciitis using US

As outlined in Table 4, 12 studies (Abdel-Wahab et al. 2008; Akfirat et al. 2003; Cheng et al. 2012; Kapoor et al. 2010; Karabay et al. 2007; Ozdemir et al. 2005; Sabir et al. 2005; Tsai et al. 2000a; Vohra et al. 2002; Walther et al. 2004; Wearing et al. 2007; Wu et al. 2011) compared PF thickness between patients with PFS and those without PFS using US in the diagnosis of PFS.

Sabir et al. (2005) and Abdel-Wahab et al. (2008) compared US and MRI with respect to their accuracy and validity in the detection of PFS. PF and heel pad thickness and other signs were measured with both imaging modalities. Strong correlation was found on PF and fat pad thickness measurements between US and MRI. US sensitivity and specificity were reported to be 80.9% and 85.7%, respectively, in Sabir et al. (2005). The statistical diagnostic accuracy of US was also reported to be 69.5% in the study carried out by Abdel-Wahab et al. (2008). Akfirat et al. (2003) compared findings from US and plain radiography, and Kapoor et al. (2010) compared US with real elastography and MRI as imaging tool references in patients with PFS.

The results indicate that US can be considered a useful imaging modality in the diagnosis and management of PFS with an acceptable diagnostic accuracy comparable to that of MRI. In addition, compared with MRI and plain

Table 4. Details of studies using US to compare PF thickness in individuals with and without PFS

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	Type of ultrasound	Position for assessment	Alignment	Measurement station	Conclusion
Tsai et al. (2000a)	102 P 33 H	To investigate US features of PFS	PF thickness Heel pad thickness	US	12-MHz linear array transducer	ATL HDI 5000	Prone with feet hanging over edge of table; real-time scanning during dynamic dorsiflexion of toes occasionally performed to stretch PF and allow easier delineation of its margins	Longitudinal	Proximal end near its insertion into calcaneus	Increased thickness and hypo-echoic PF are consistent with US findings in patients exhibiting PFS.
Vohra et al. (2002)	109 P	To evaluate thickness of medial, central and lateral bands of PF using US techniques	PF thickness	US	7-MHz linear array transducer	Accustom 128 XT	Supine with feet hanging over edge of table, with dorsiflexion of toes to stretch PF to allow delineation of its margins clearly	Longitudinal	Point nearest calcaneal insertion of PF	There were significant differences in thickness of the three PF bands in symptomatic patients. PF index (ratio of mean thickness of symptomatic medial, central and lateral PF bands to that of asymptomatic bands) was established.
Akfirat et al. (2003)	40 P	To study high-frequency sonography in examination of PFS	PF thickness	US Radiography MRI	7.5-MHz linear array transducer	GE LOGIQ 200 Pro series	Prone with free ankle motion to examine PF easily	Longitudinal	Insertion of calcaneus as bone landmark	US should be considered early in management of PF and could be used as initial imaging modality for investigation of patients with PFS.
Walther et al. (2004)	20 P 20 H	To characterize PDU findings in PFS	Pain Moderate or marked hyperemia	VAS PDU US	7.5-MHz linear array transducer	Siemens	Prone with feet hanging freely over table	Longitudinal view (accurate positioning of transducer confirmed on transverse view of heel)	PF, to visualize the first 3 cm PF from its insertion into calcaneus its proximal end near its insertion into calcaneus	PDU improves value of US as non-invasive technique for diagnosis of PFS, providing additional information on local hyperemia.
Ozdemir et al. (2005)	39 P 22 H	To investigate role of US in diagnosis of PFS	PF thickness	US	7.5-MHz linear array transducer	GE LOGIQ 300 Pro	Prone, full knee extension and 90° dorsiflexion of ankle	Longitudinal	5 mm distal to calcaneal insertion of plantar aponeurosis	US may detect relatively small differences in PF thickness, even in clinically unequivocal PFS
Sabir et al. (2005)	77 P	To investigate efficacy of US in detection of PFS compared with MRI findings in patients with inferior heel pain	PF thickness Heel pad thickness	US MRI	6.0- to 9.0-MHz linear array transducer	LOGIQ 500 Pro	Prone with full knee extension and 90° dorsiflexion of ankle	Longitudinal	PF crosses anterior aspect of inferior border of calcaneus	Although MRI is modality of choice in morphologic assessment of different PF lesions, US can also serve as effective tool and may substitute for MRI in diagnosis of PFS.

(*Continued*)

Table 4. (*Continued*)

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	Type of ultrasound	Position for assessment	Alignment	Measurement station	Conclusion
Karabay et al. (2007)	23 P 23 H	To evaluate patients with PFS via US compared with their asymptomatic feet and a control group of 23 people	PF thickness Heel pad thickness	US	7.5- to 9-MHz linear array transducer	Siemens Sonoline Sienna	NR	NR	PF proximal end near its insertion into calcaneus (1 cm away from insertion point to bone)	US seems to be valuable, non-invasive diagnostic tool for evaluation of PFS.
Wearing et al. (2007)	10 P 10 H	To compare US measures of PF thickness and radiographic measures of arch shape and regional loading of foot during gait in individuals with and without unilateral PFS	Pain PF thickness Static arch H angle	VAS US Pressure plate	12- to 5-MHz linear array transducer	HDI 5000	Prone with ankle in neutral (0° of dorsiflexion and plantar flexion)	Longitudinal	5 mm from insertion, at anterior aspect of inferior border of calcaneus	PF thickness and pain in PFS are associated with regional loading and static shape of arch.
Abdel-Wahab et al. (2008)	17 P (23 F) 11 H (22 F)	To compare high-resolution US with MRI to assess its value as alternative modality to confirm clinical diagnosis of PFS	PF thickness Abnormal signal Subcutaneous edema Fluid collection Fiber rupture Calcaneal spur	US MRI	5- to 17-MHz line array transducer 1.5-T magnet	Philips iU22 Siemens Avanto	Prone with feet dorsiflexed and hanging over edge of table	Longitudinal	Calcaneal insertion	Sonographic diagnosis of PFS is useful tool with acceptable diagnostic accuracy comparable to that of MRI.
Kapoor et al. (2010)	25 P	To evaluate and compare roles of elastography, US and MRI in patients with PFS	Echogenicity, margins and thickness of PF	US MRI	9-MHz linear array transducer	Acuson 2000, 1.5-T system Siemens Maestro class	Prone	Longitudinal	NR	Combination of elastography with US improves accuracy from 68% to 96% and also stages extent of disease, with the results being comparable to those of MRI.
Wu et al. (2011)	13 P 40 H	To compare stiffness of PF using US in healthy patients of different ages, as well as patients with PFS	PF thickness PF stiffness	US	6- to 12-MHz linear array transducer	Acuson S2000	Prone with 90° of knee flexion in neutral ankle position	Longitudinal	Anterior edge of inferior calcaneal border vertically to inferior border of PF	US revealed that PF softens with age and in patients with PFS.
Cheng et al. (2012)	11 P (20 F) 26 H (52 F)	To evaluate intra- and inter-rater reliability of US measurements of thickness and echogenicity of PF	PF thickness	US	5- to 12-MHz linear array transducer	Philips HD3	Prone with feet hanging freely over table	Longitudinal and transverse planes	Thickest part of PF at its insertion onto calcaneal bone	Reliability of US examination of PF thickness is high. Longitudinal instead of transverse scanning is recommended for imaging PF.

PF = plantar fascia; PFS = plantar fasciitis; US = ultrasonography; P = Patients; H = Healthy patients; PDU = Power Doppler ultrasonography; VAS = visual analogue scale; MRI = magnetic resonance imaging; F = Feet; BMI = body mass index; VI = Vascular index; NR = not reported.

Table 5. Details of studies using US as a guide in patients with PFS

Authors	Sample	Purpose	Outcome measure	Measurement tools	Type of probe	Type of ultrasound	Position for assessment	Alignment	Measurement station	Conclusion
Buchbinder et al. (2002)	178 P	To determine whether US-guided ESWT reduces pain and improves function in patients with PFS	Pain Function Quality of life	VAS Maryland foot score Walking ability SF36 score Problem elicitation technique score	NR	Dornier Epos Ultra	Sitting in chair with affected foot resting on foam support and footstool	NR	Water cushion and transducer placed over heel and positioned so that origin of PF adjacent to calcaneum was visible	There is no evidence to support a beneficial effect on pain, function and quality of life of US-guided ESWT over placebo in patients with US-proven PFS.
Theodore et al. (2004)	150 P	To assess clinical safety profile and effectiveness of US-guided ESWT for treatment of PFS	Pain	VAS	NR	Dornier Epos Ultra	Position of shock wave source was modified during treatment using US image and patient feedback to ensure that shock wave focus was directed precisely into pain epicenter	NR	NR	US-guided ESWT represents tolerable treatment option for chronic proximal PFS
Folman et al. (2005)	32 P	To assess US-guided needle fasciotomy	Pain	VAS	10-MHz linear array transducer	NR	NR	NR	NR	US-guided needle fasciotomy is tolerable and effective method for relief of conservatively unmanageable heel pain caused by PFS.
Hyer et al. (2005)	30 P (39 F)	To determine success of US-guided ESWT for treatment of recalcitrant PFS	Pain	VAS	NR	Dornier Epos Ultra	NR	Longitudinal	Point of maximal tenderness; US screen was used to visualize PF and plantar cortex of calcaneus	These early results indicate US-guided ESWT may be useful tool in treatment of chronic PFS.
Ryan et al. (2009)	20 P	To report on effectiveness of US-guided injections in reducing pain associated with chronic PFS	Pain	VAS	5- to 12-MHz and 7- to 15-MHz linear array high-resolution transducer	Philips HDL 5000	Prone	Longitudinal and transverse	NR	US-guided injections elicited good clinical response in patients with chronic PFS insofar as pain was reduced during rest and activity.
Vohra and Japour (2009)	41 P (46 F)	To offer the surgeon clear visualization of anatomy at the surgical site with US-guided PF release	Function	AOFAS hindfoot rating scale	7-MHz linear array transducer	Accustom 128 XT	Supine with feet hanging over edge of table, with dorsiflexion of toes to stretch PF to delineate its margins	Longitudinal	Point nearest calcaneal insertion of PF	US-guided PF release technique is practical surgical procedure for relief of chronic PFS

US = ultrasonography; PFS = plantar fasciitis; P = patients; F = feet; ESWT = extracorporeal shock wave therapy; VAS = visual analogue scale; SF = Short Form (36) Health Survey; AOFAS = American Orthopaedic Foot and Ankle Society; NR = not reported.

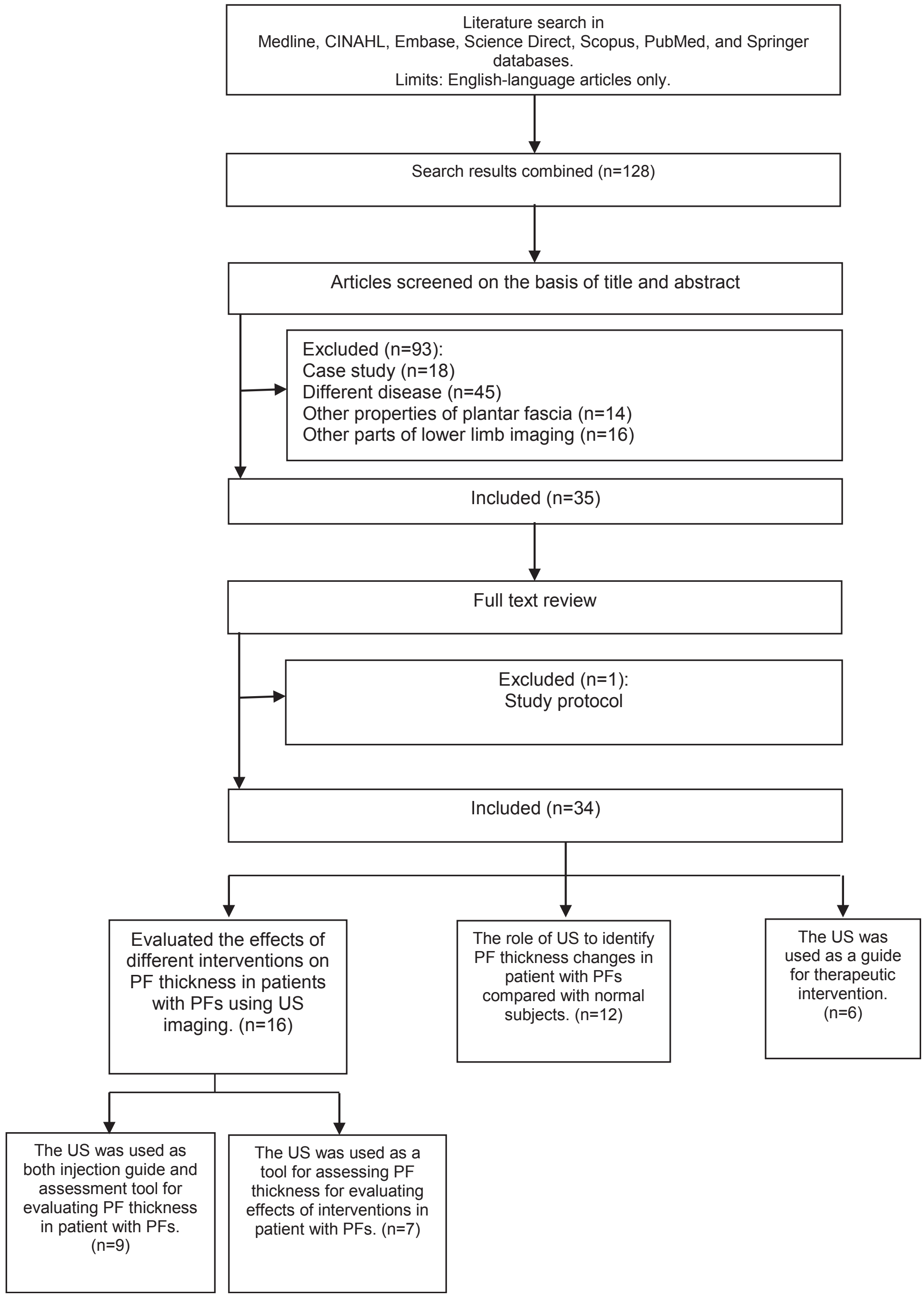

Fig. 1. Flow diagram of study selection. PF = plantar fascia; PFS = plantar fasciitis; US = ultrasound.

radiography, US is more cost effective, faster and easier to use, and more patient friendly and is non-invasive and radiation free.

The remaining 8 studies (Cheng et al. 2012; Karabay et al. 2007; Ozdemir et al. 2005; Tsai et al. 2000a; Vohra et al. 2002; Walther et al. 2004; Wearing et al. 2007; Wu et al. 2011), used US to evaluate PF in patients with PFSs and subjects without PFS. For example, Wearing et al. (2007) compared US measures of PF thickness and radiographic measures of arch shape and regional loading of the foot during gait in 10 individuals with and without unilateral PF thickness. Meanwhile, static arch angle was determined from bilateral sagittal US and weight-bearing lateral foot roentgenograms. Regional plantar loading was estimated from a pressure plate. The PF of the symptomatic limb was thicker than both the PF of the asymptomatic limb and the PF of a matched control group limb. PF thickness was positively correlated with arch angle in symptomatic and asymptomatic feet and with peak regional loading of the midfoot in the symptomatic limb.

All studies investigating US imaging reported that US appears to be a useful, reliable and valid tool for discriminating PF thickness in individuals with and without PFS. It can also be considered as an objective tool that provides sufficient and appropriate information for physicians to confirm the diagnosis of PFS.

Application of US as a guide for therapeutic intervention in patients with PFS.

As outlined in Table 5, six studies (Buchbinder et al. 2002; Folman et al. 2005; Hyer et al. 2005; Ryan et al. 2009; Theodore et al. 2004; Vohra and Japour 2009) evaluated the effect of US as a guide for therapeutic interventions in patients with PFS.

For example, the success of US-guided ESWT for the treatment of recalcitrant PFS was evaluated by Hyer et al. (2005), who assessed pain intensity using the visual analogue scale. After 124 d of follow-up, the results indicated that US-guided ESWT may be a useful tool in the treatment of chronic PFS. US guidance for fasciotomy of PF in patients with PFS was investigated by Vohra and Japour (2009) and Folman et al. (2005). They concluded that US-guided PF release is a practical surgical procedure for the relief of chronic PFS, with fewer side effects because the surgeon is able to clearly visualize the PF. Ryan et al. (2009) reported that US guidance improved injection accuracy and significantly reduced pain intensity associated with chronic PFS. Buchbinder et al. (2002), Hyer et al. (2005), and Theodore et al. (2004) used US guidance to focus ESWT on the exact location of the pain.

These results indicate that US guidance allows direct real-time visualization and improves accuracy in the delivery of interventions in patients with PFS.

CONCLUSIONS

The purpose of this study was to systematically review published studies from 2000 to 2012 concerning the application of US in the assessment of PF in patients with PFS. There were wide variations in methodology, US equipment, sample size and other factors. The results indicate that US is an accurate, reliable and non-invasive imaging technique for assessing PF thickness, monitoring effects of different interventions and guiding therapeutic interventions in patients with PFS.

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